R&D on Hybrid Thin-Film Superconducting Cavities for ADMX/ADMX-HF

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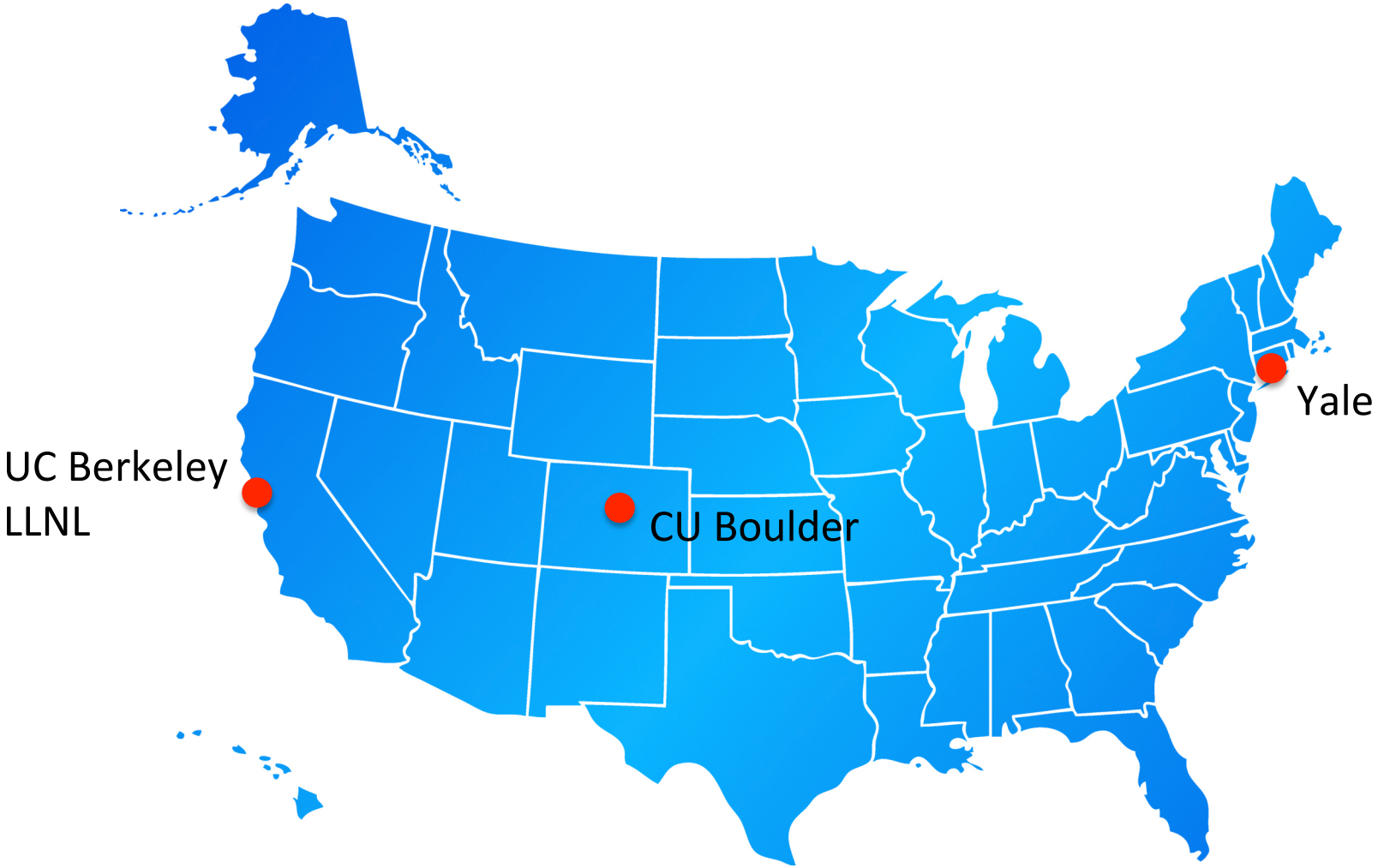
ADMX-HF

Axion Dark Matter eXperiment – High Frequencies



Outline

- Motivation for Hybrid Thin-Film Superconducting Cavities
- RF Plasma Deposition system
- History of the ADMX-HF systems at Berkeley, LLNL and Yale
- First results from the UCB system
- Next steps

What's the point?

$$P \propto g^2 \cdot B^2 V \cdot \min(Q_L, Q_a)$$

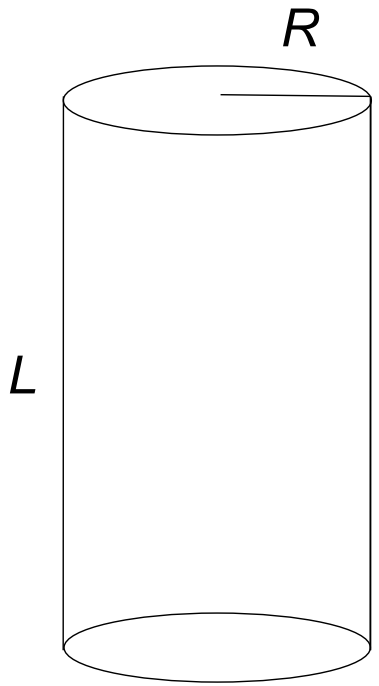
$$\frac{1}{f} \cdot \frac{df}{dt} \propto g^4 \cdot B^4 V^2 \cdot \min(Q_L, Q_a)$$

For copper cavities, $Q_a \sim 10^6$, whereas $Q_L \sim 50{,}000$

If you could increase Q_L by a factor of *e.g.* x10 :

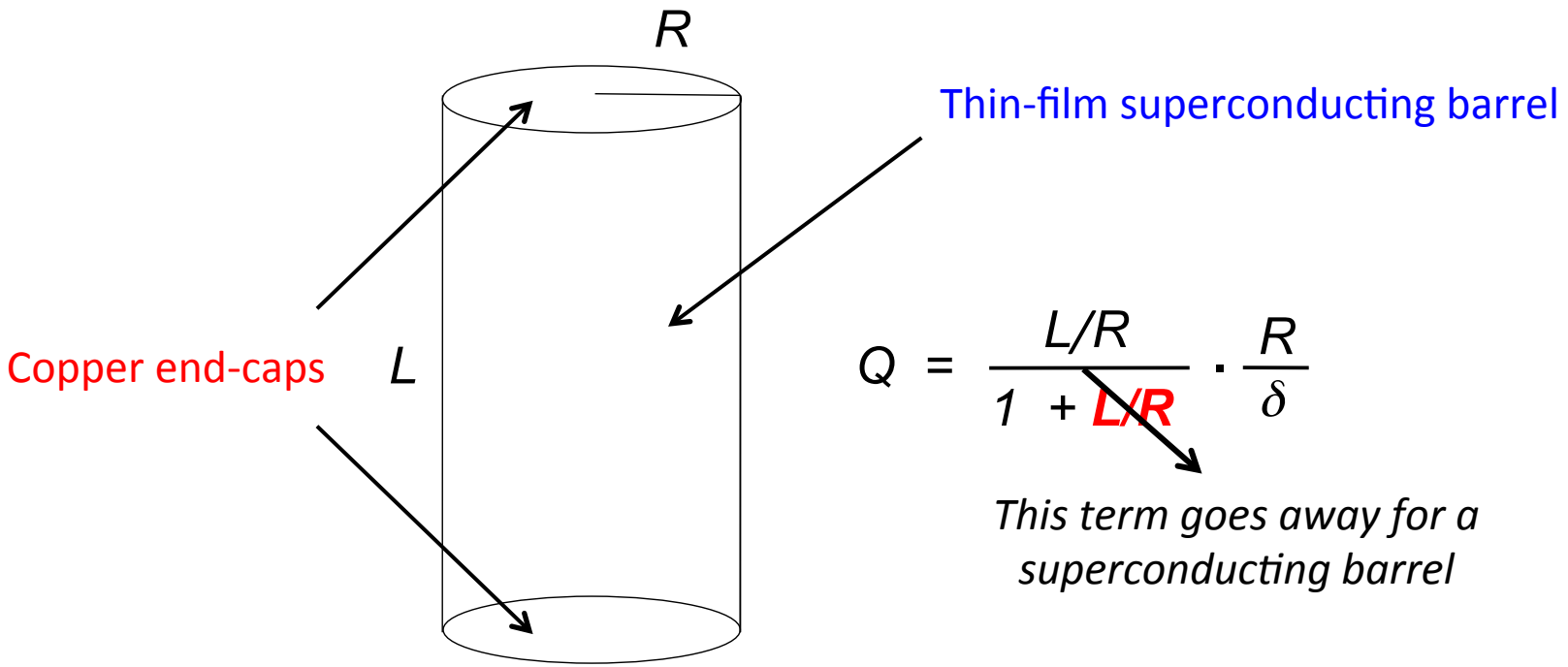
- P would increase by x10
- df/dt would increase by x10 *(for constant g)*
- g would improve by ÷1.8 *(for constant scan speed)*

Q of the TM_{010} mode for a conventional Cu cavity:



$$Q = \frac{L/R}{1 + L/R} \cdot \frac{R}{\delta}$$

The concept of a hybrid superconducting cavity:



$$Q_{hybrid} = (1 + L/R) \cdot Q_{cu}$$

For typical ADMX cavity, L/R = 5, enhancement factor = 6

Univ. Florida (Xi et al.) validated the science basis

PRL 105, 257006 (2010) PHYSICAL REVIEW LETTERS week ending 17 DECEMBER 2010

Far-Infrared Conductivity Measurements of Pair Breaking in Superconducting $Nb_{0.5}Ti_{0.5}N$ Thin Films Induced by an External Magnetic Field

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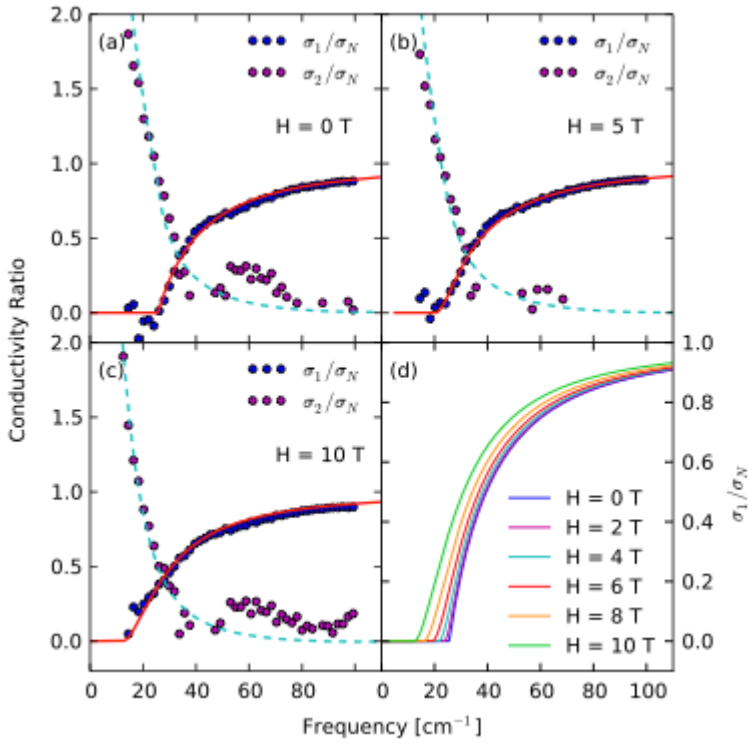
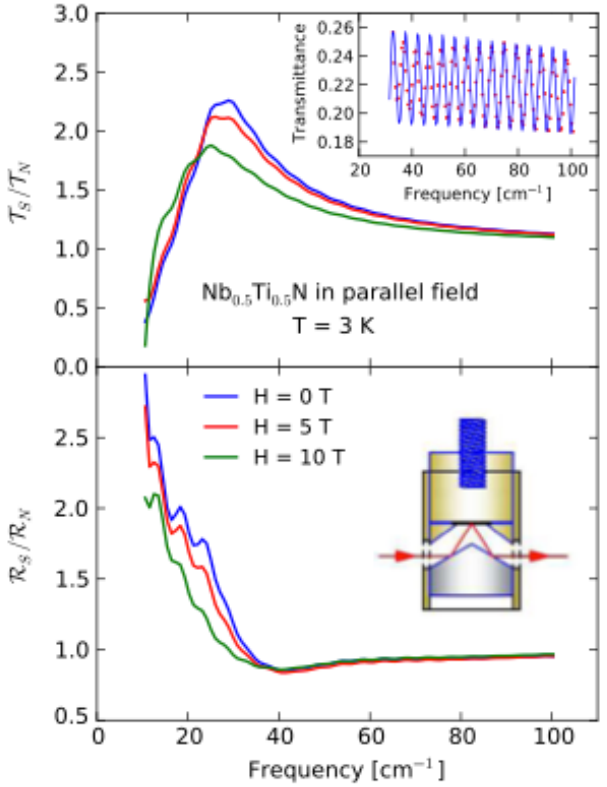
We report the complex optical conductivity of a superconducting thin film of $Nb_{0.5}Ti_{0.5}N$ in an external magnetic field. The field was applied parallel to the film surface and the conductivity extracted from far-infrared transmission and reflection measurements. The real part shows the superconducting gap, which we observe to be suppressed by the applied magnetic field. We compare our results with the pair-breaking theory of Abrikosov and Gor'kov and confirm directly the theory's validity for the optical conductivity.

DOI: 10.1103/PhysRevLett.105.257006 PACS numbers: 74.78.−w, 74.25.Ha, 78.20.−e, 78.30.−j





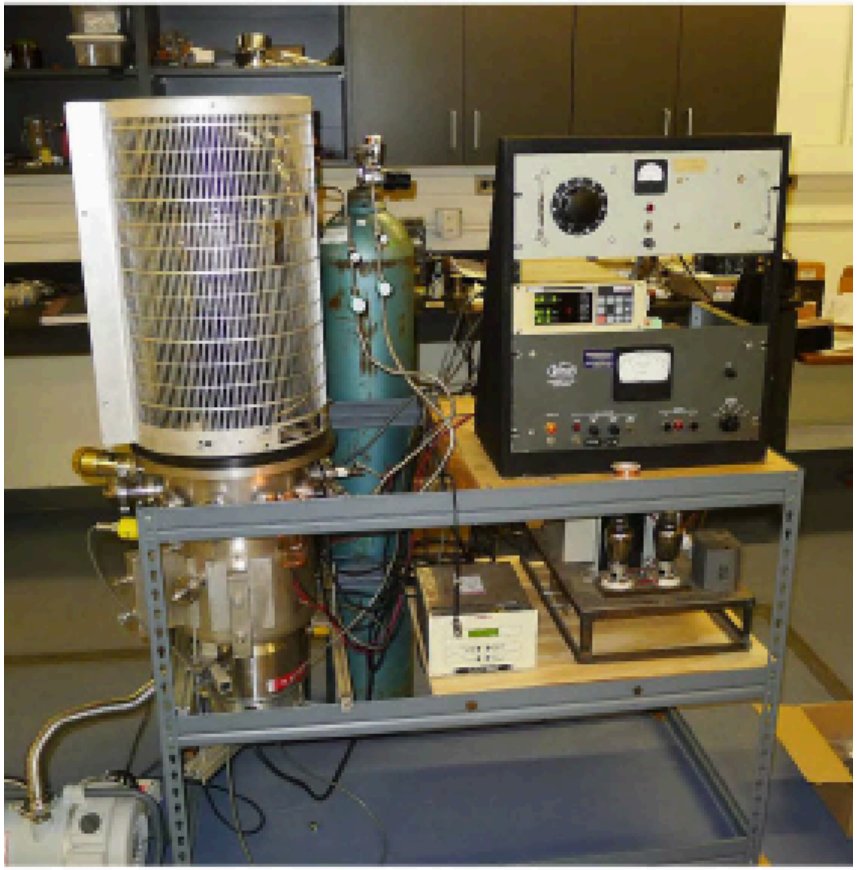
10 nm $Nb_{0.5}Ti_{0.5}N$ is perfect

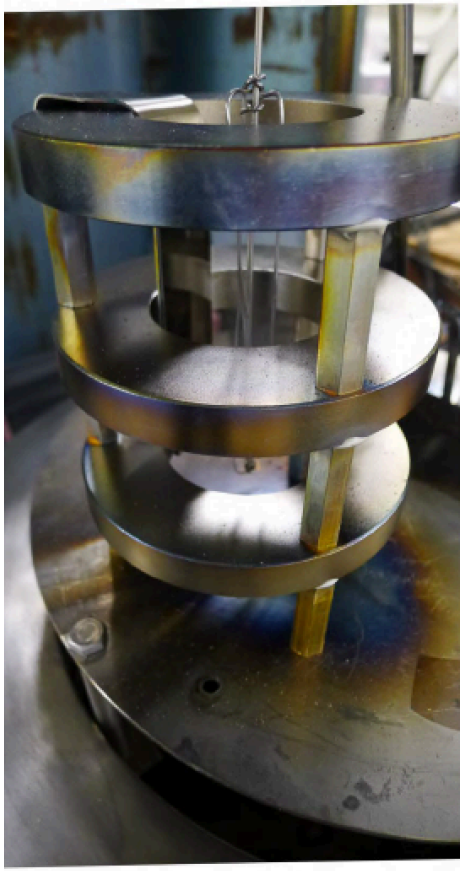
Supports $B_{||}$ up to 10 Tesla

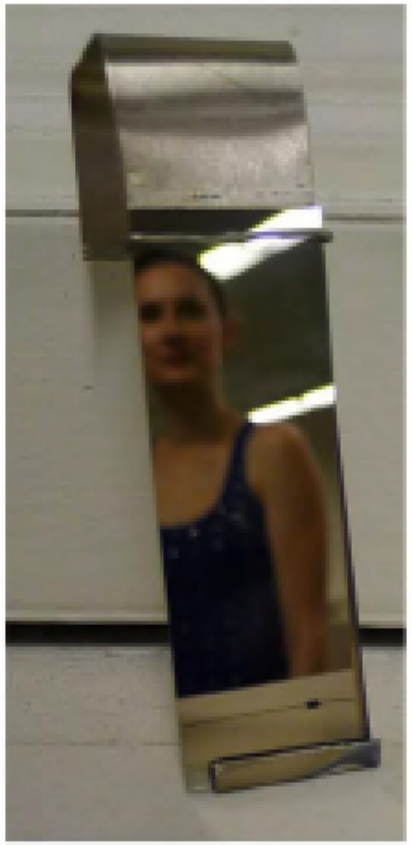
History of the Hybrid Type II TFS Cavity idea

- R&D effort for Hybrid TFS cavity proposed to ADMX collaboration meeting 8/2011
- At the same meeting Prof. Ka-Ngo Leung (UCB NE) provided the technical solution for coating interior cylindrical surfaces
- He had successfully deposited TiN on 2.2 km of beam-pipe in the Low Energy Ring of the SLAC-LBNL-LLNL PEP II B Factory

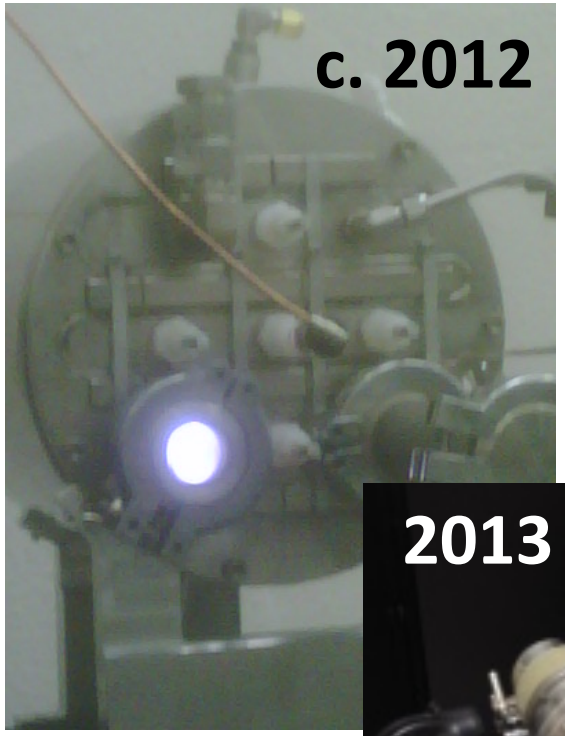
Yale got in the game

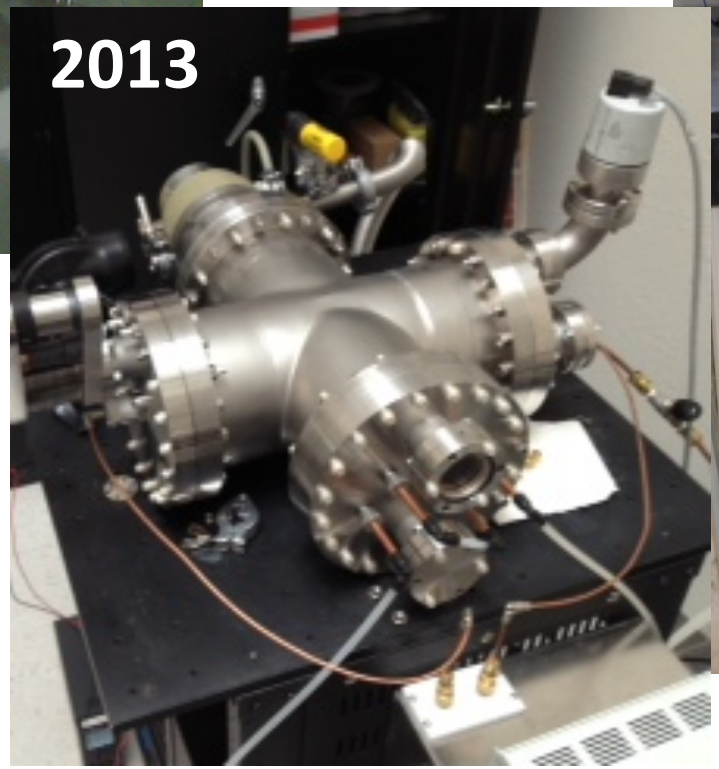


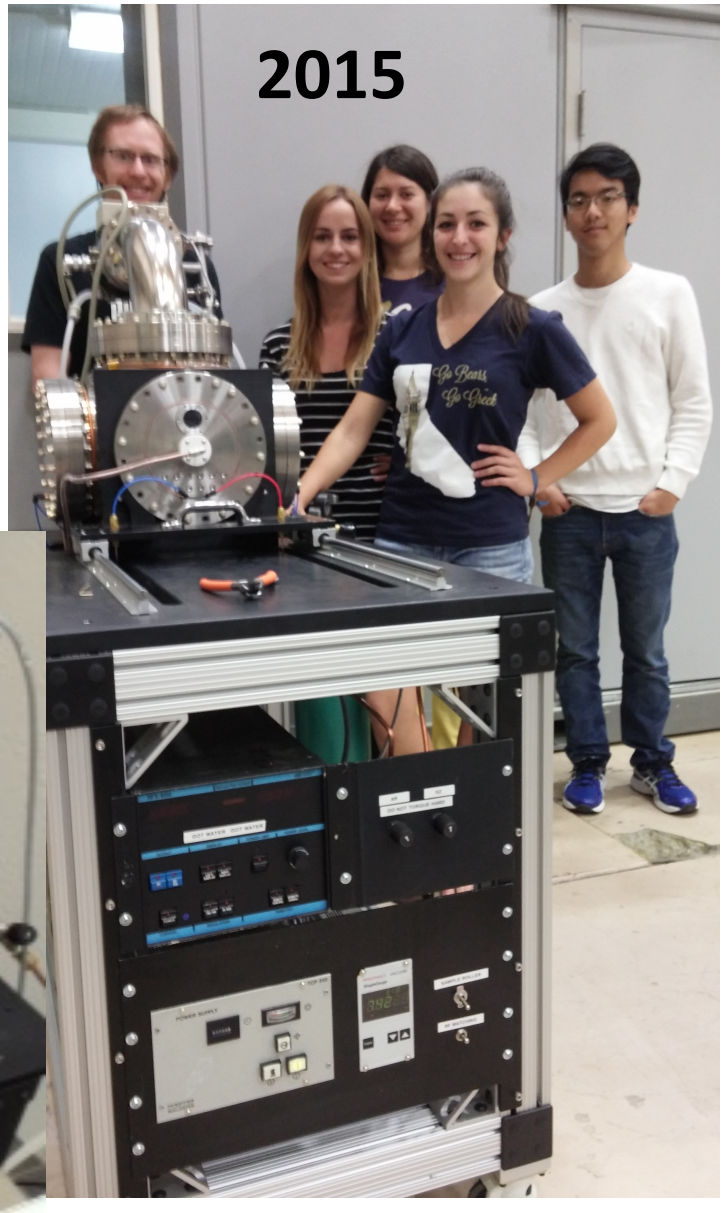




G&J Jones Co. made three RF plasma deposition units for us

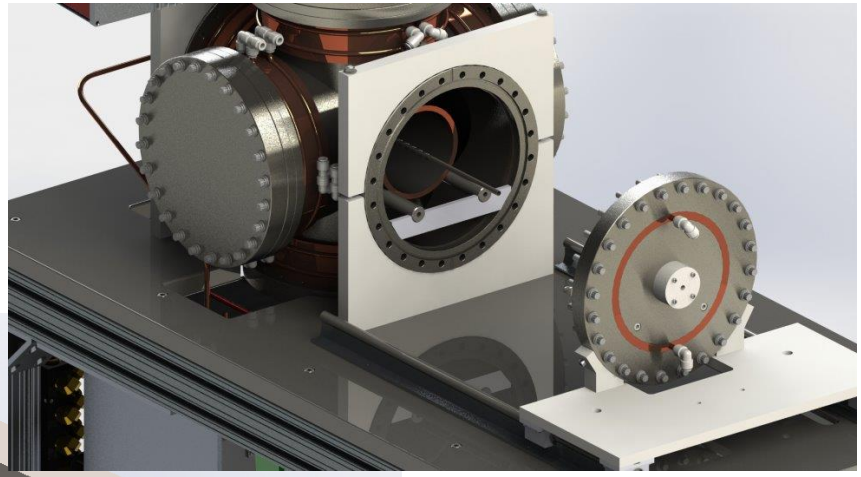


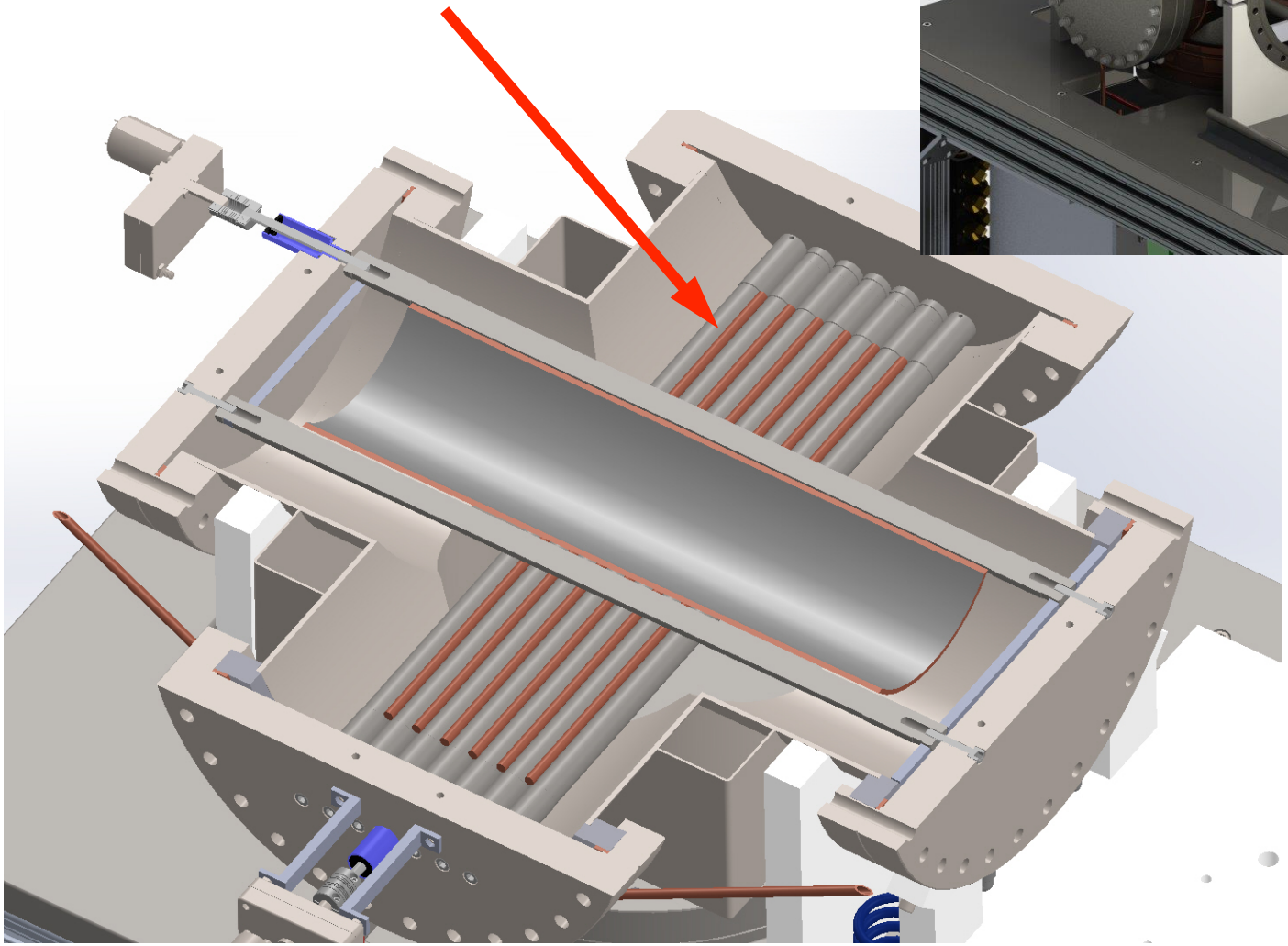




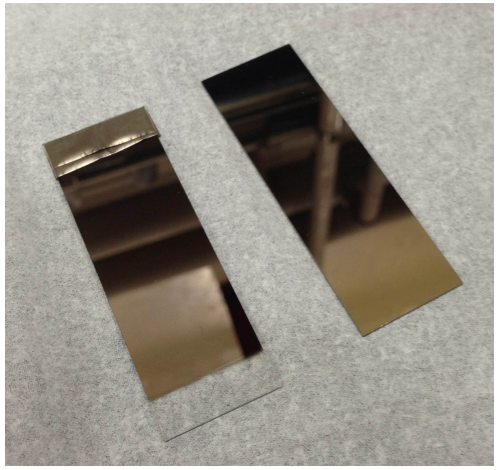
Berkeley unit can coat both barrels (concave) & rods (convex)

The “Hot Dog Roller”

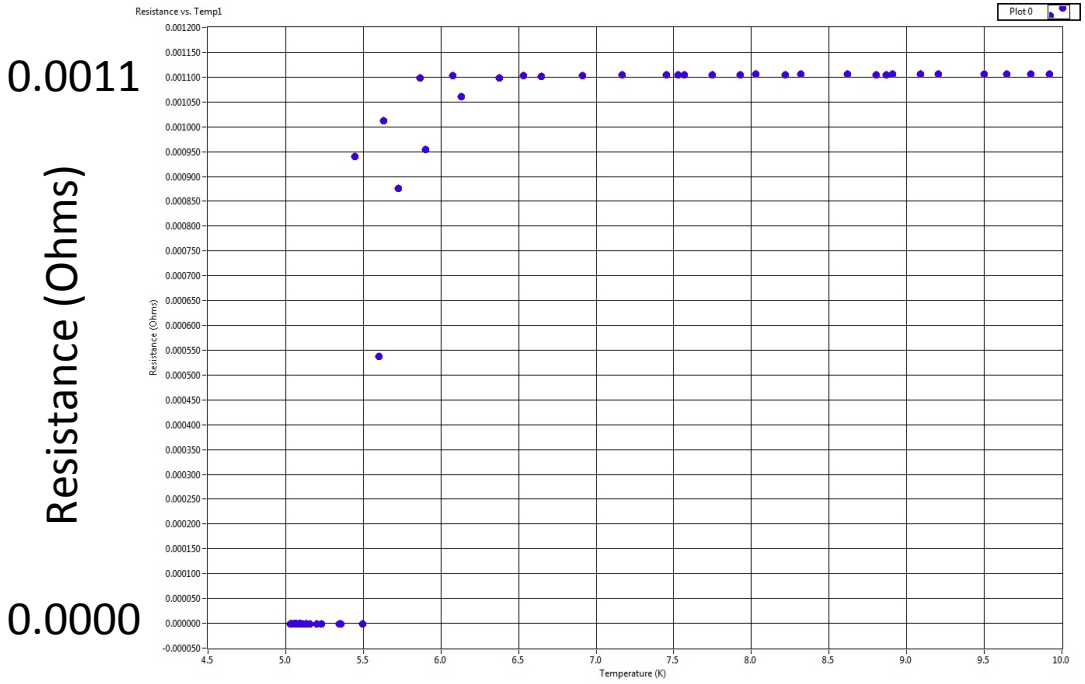




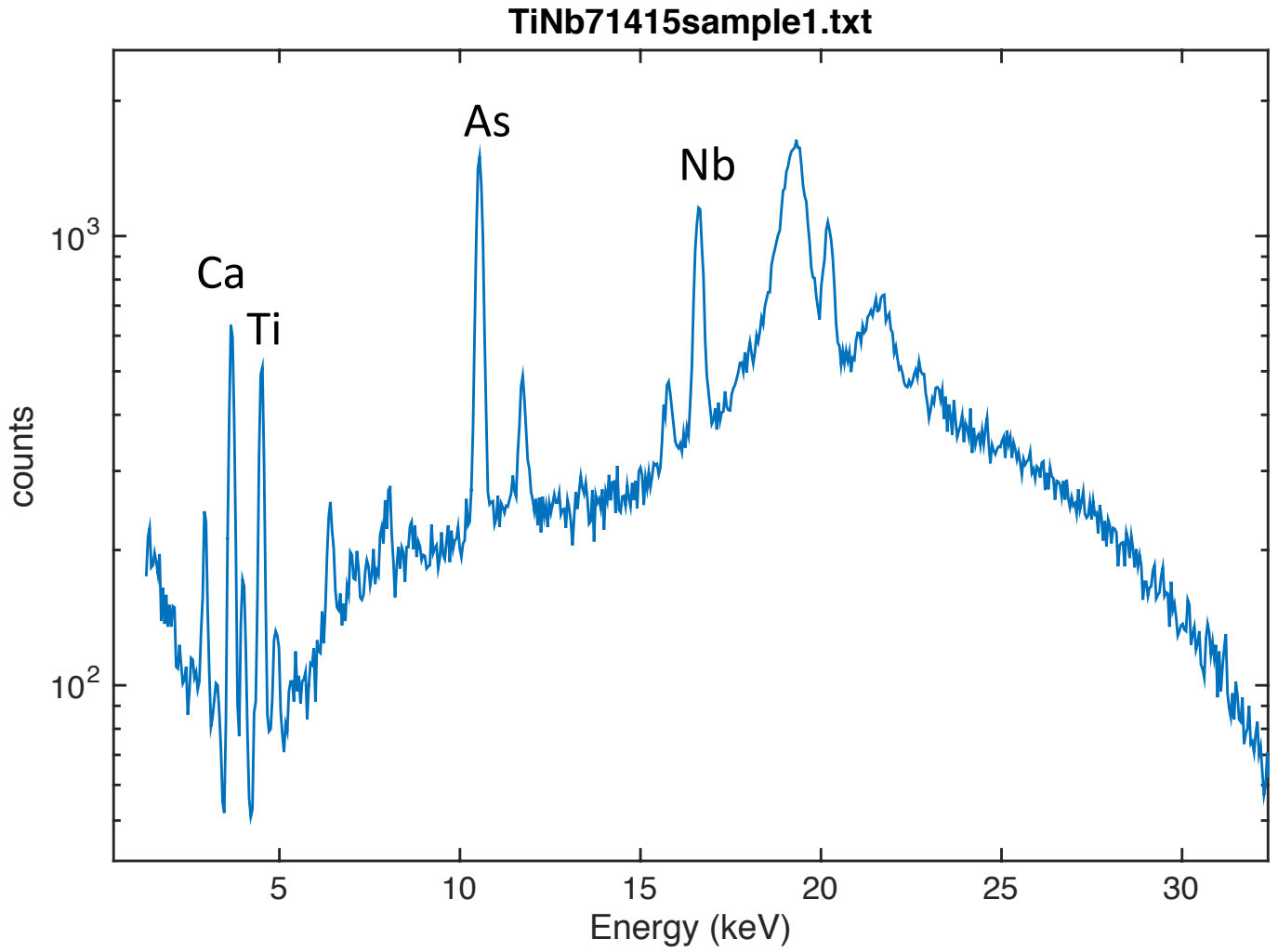
Characterization



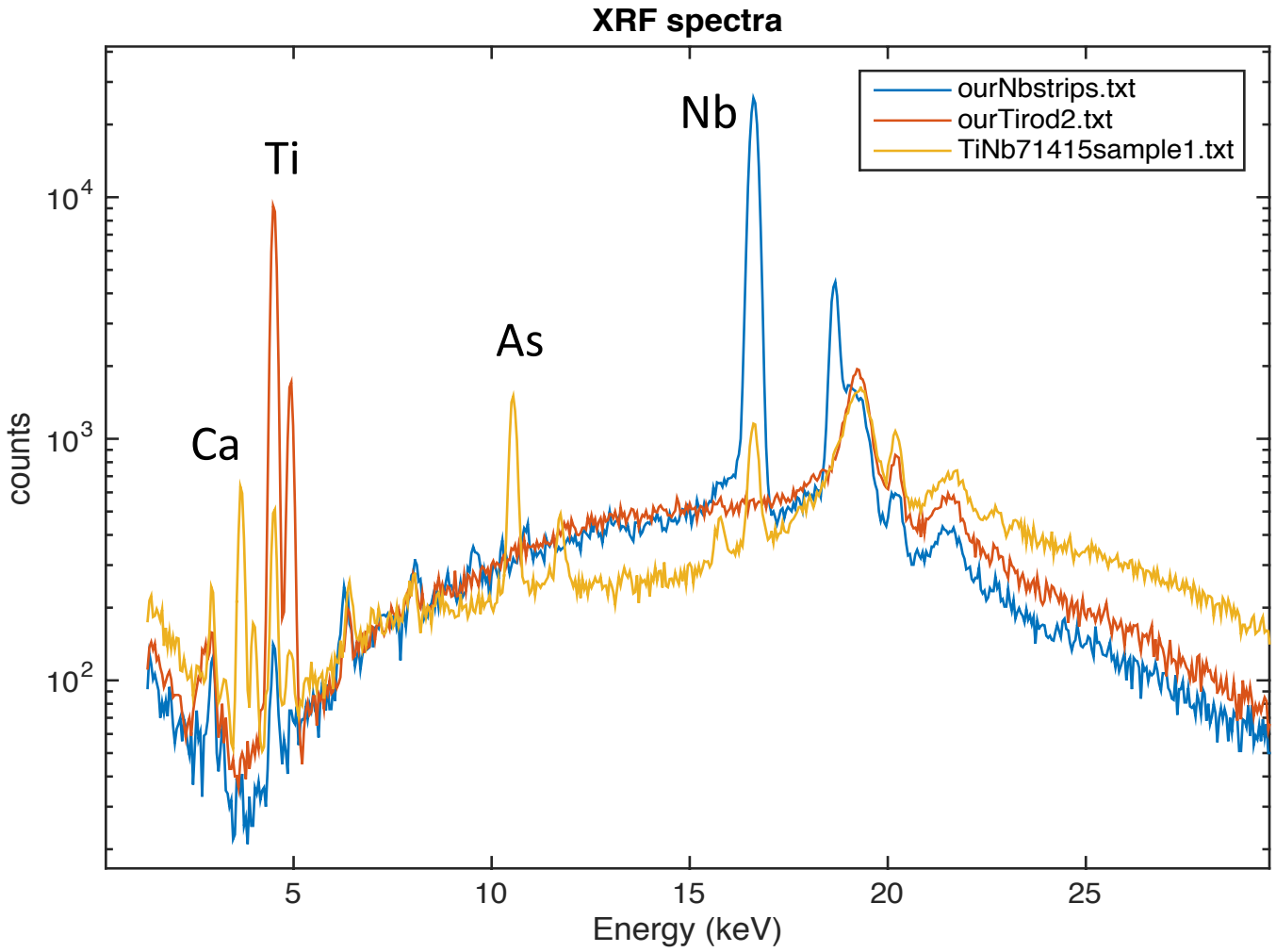
- Four-wire measurement
  - Resistance
- X-ray fluorescence
  - Composition
  - Thickness?
- Rutherford backscattering
  - Composition
  - Thickness



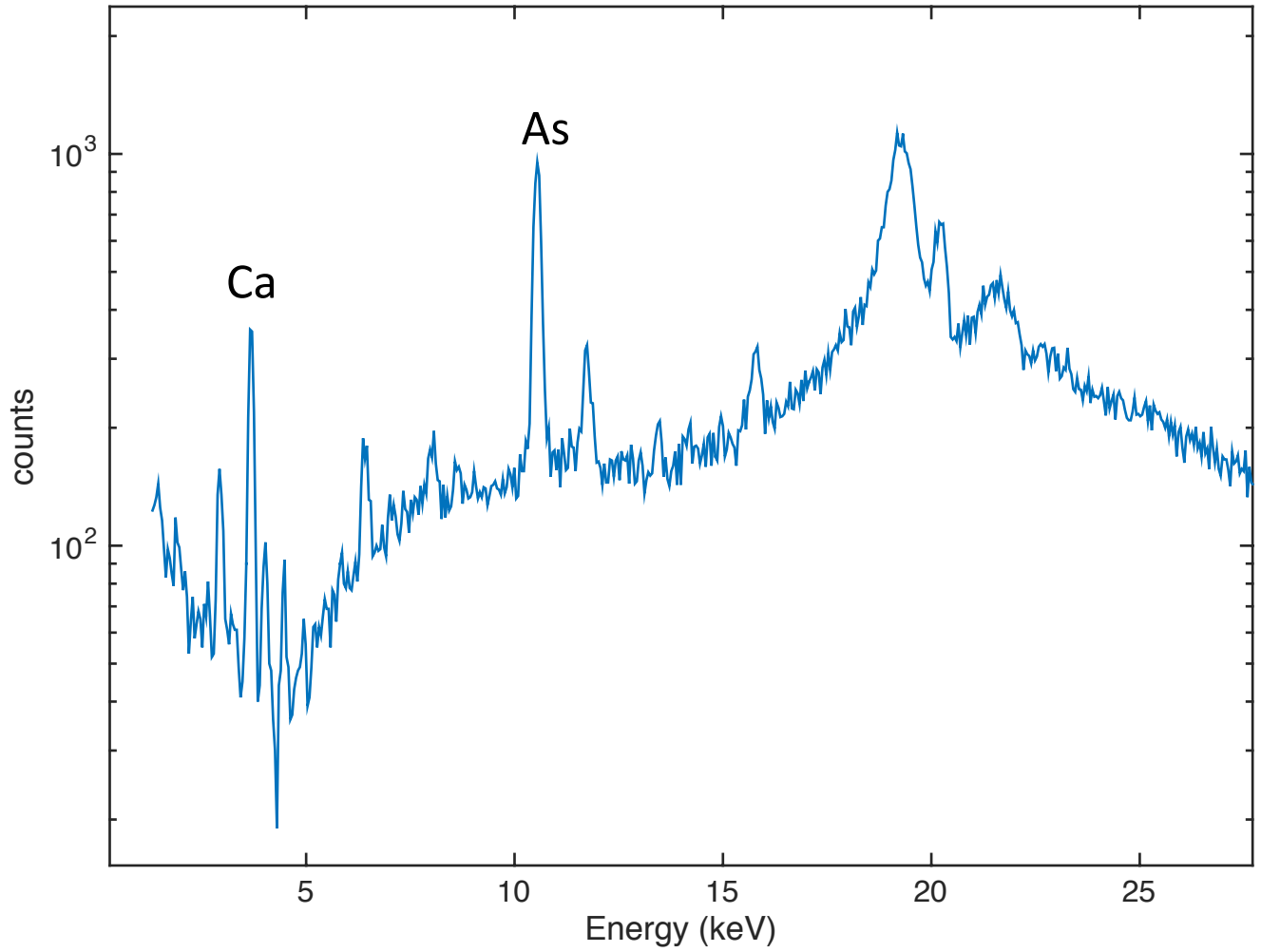
XRF: a mystery…

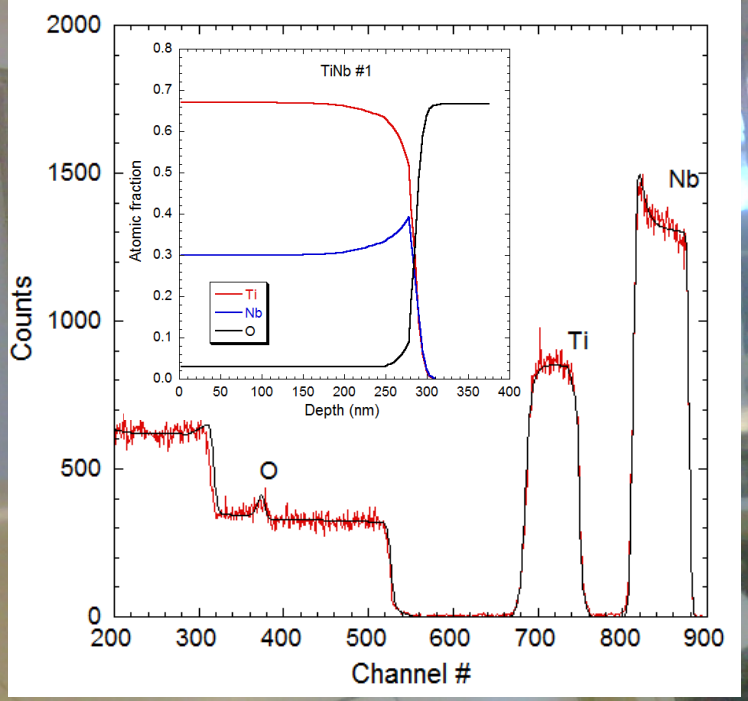


XRF: a mystery…



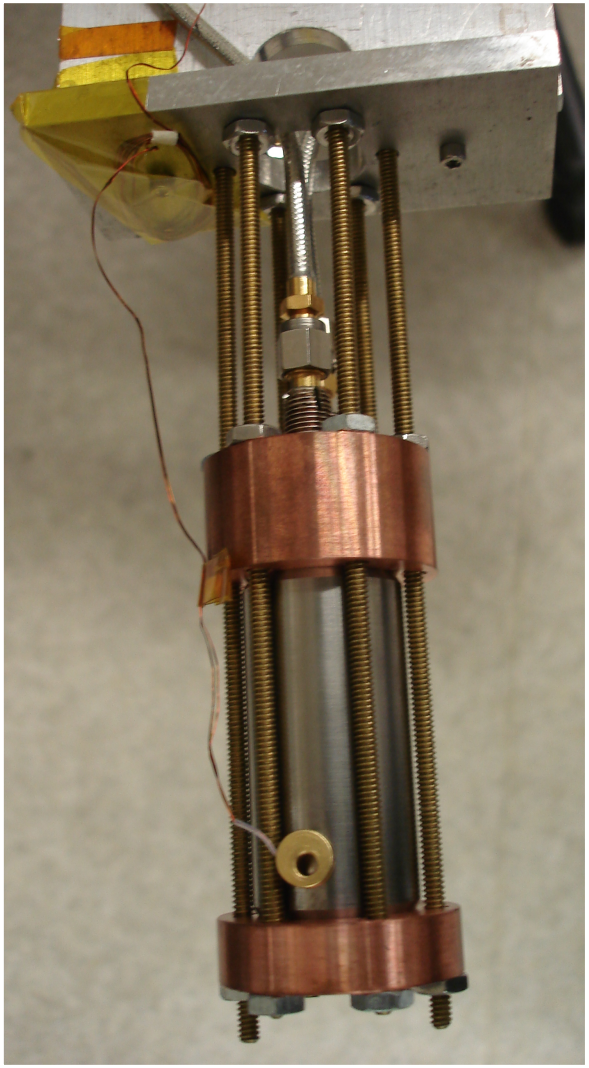
Mystery solved: microscope slide!

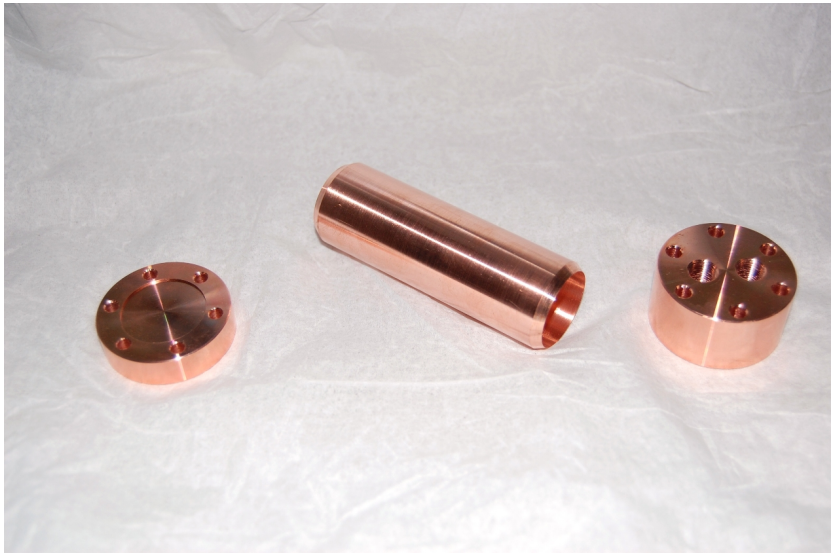




LBNL Rutherford Backscattering System

10 GHz prototype cavities ("salt shaker cavities")





We "rediscover" the proximity effect after 50 or 60 years, i.e. a superconducting thin film on a normal conducting substrate doesn't work. Thus ceramic or anodized aluminum substrate next.*

"Several months in the lab saved us several hours in the library." S.K. Lamoreaux

* C.R. Hannum & R.E. Wyatt, MS Thesis, NPS 1963

Next steps

- “Salt-shaker” cavity depositions
- Multi-layer films!
  - Perfectly reflecting RF deposition will need to be a multilayer of alternating TFS (~ 10 nm) and thin insulating layers


Thank you!!!